MEASUREMENT OF VOLTAGE DISTRIBUTION ON HIGH VOLTAGE SUSPENSION INSULATOR STRING UNDER POLLUTED CONDITION

A Thesis Submitted in Partial Fulfilment
of the Requirements for the Award of the Degree of

Master of Technology

in

Electrical Engineering
(Industrial Electronics)

by

Simanta Kumar Samal
(Roll No: 213EE5350)

May, 2015

Department of Electrical Engineering
National Institute of Technology
Rourkela-769008
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Under the Guidance of
Prof. Subrata Karmakar

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Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "**Measurement of Voltage Distribution on High Voltage Suspension Insulator String Under Polluted Condition**" submitted by **Simanta Kumar Samal** in partial fulfilment of the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in Industrial Electronics during 2014 - 2015 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Prof. S. Karmakar
Department of Electrical Engineering
National Institute of Technology
Rourkela-769008

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Simanta Kumar Samal
(Roll No. 213EE5350)

ABSTRACT

From electrical engineering point of view insulator plays an important role. As it is used as basic element in overhead transmission and distribution networks. They are not only to insulate the power line but also to carry the weight of the transmission line conductor. Voltage and electric field are the main factors to withstand the insulation. Therefore it is very much essential for insulator string to relate the potential distribution and electric field distribution to that of the respective ideal string accurately. In operational high voltage, the non-uniformity of potential distribution across the insulator string is due to the presence of stray capacitance. Also, the performance of insulator (voltage distribution, electric field distribution) varies by the deposition of environmental pollutants either uniformly distributed or non-uniformly distributed on the surface of insulator, which deteriorated by the help of captivation of moisture particles sharply. So to sort out this dilemma practically by the help of a full equivalent circuit in which the properties of insulating material and stray capacitance effect should be taken for proper consideration, which is derived from the Finite Element Method Based Software and executed in the Ansys Maxwell software package for the calculation of potential distribution, electric field distribution and also electric field vector distribution throughout the specified string with and without pollutants in proper power frequency along with desired voltage. A comparison between normal and polluted (coastal polluted and industrial polluted) creepage voltage vs creepage distance in graphical form is studied by using Matlab. Finally a voltage gradient and electric field comparison is studied by using Matlab.

CONTENTS

LIST OF ABBREVIATION

Symbols	Abbreviation
C	Capacitance between each insulator unit and line conductor (line capacitance).
C'	Capacitance between each unit and ground (stray capacitance).
I_{n+1}	Current flow in the $(n+1)^{th}$ unit due to current in n^{th} unit line capacitance and that of stray capacitance.
ΔV_{n+1}	Voltage across $(n+1)^{th}$ unit due to n^{th}unit line capacitance voltage and that of stray capacitance.
X_c	Capacitive reactance of line capacitance.
ω	Power frequency in (rad/sec).
I_n'	Current flow in the n^{th} unit of stray capacitance.
X_c'	Capacitive reactance of stray capacitance.
V_{n+1}	Voltage of $(n+1)^{th}$unit only due to line capacitance.
I_n	Current in the n^{th} unit line capacitance.
ΔV_n	Voltage across n^{th} unit due to both line capacitance voltage and that of stray capacitance.
m	Capacitance ratio or de-multiplication factor.
ΔV_0	Voltage across first unit from tower side.
ΔV_1	Voltage across second unit from tower side.
ΔV_2	Voltage across third unit from tower side.

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CHAPTER-1

INTRODUCTION

1.1 INTRODUCTION

An electrical insulator is nothing but a material whose internal electric charges do not flow freely and hence make it very hard to conduct an electric current under the influence of an electric field. That's why it plays an important role in electrical system. In the whole universe a perfect insulator does not exist, because a portion of the insulator could become electrically conductive, when the voltage applied across it exceeds the breakdown voltage. Therefore insulator is one of the most vital component of power transmission and distribution network [1], [3]. At the lower utilization voltage the insulation completely surrounds the live conductor and hence acts as a barrier which keeps the live conductors unreachable from human being or animals. It is mainly house warring and domestics purpose where the applied voltage for services is lower. In the other hand for high voltage overhead transmission and distribution the transmission towers or poles support the lines and insulators are used to insulate the live conductor from the transmission towers. At the same time the insulators used in transmission and distribution system are also required to carry large tensional or compressive load [7]. Depending upon the applied voltage a various type of insulators are used in transmission and distribution network. Such as pin insulator (Low voltage up to 33 kV), shackle insulator (Low voltage distribution network), suspension insulator (High voltage transmission network), strain insulator (High voltage transmission network), these are mainly used for transmission and distribution. The shackle insulator is replaced by strain insulator in high voltage transmission network whereas pin insulator is replaced by suspension insulator. But now a days shackle insulators are not used because of the increased use of underground cable in distribution network. Suspension insulators are widely used in transmission network, i.e. in high voltage lines. The knowledge of the voltage distribution and electric field within and around high voltage insulators is of paramount importance for the engineer involved in the design of power lines insulation [24].

Mainly the overhead line insulators are failed due to occurrence of flashover which normally creates in between the line and earth when the voltage increases to reach a particular value in the system. Puncture of insulator unit is occurred because of maximum arcing at the time of flashover [11]. Therefore insulation materials have some specific properties. Such as,

1. It must be mechanically strong, so that to carry tension and weight of the conductors.
2. The dielectric strength must be very high, so that to withstand the high voltage stress.
3. The insulation resistance must be high, so that to prevent the leakage current to the earth.
4. It must be free from unwanted impurities and should not be porous.
5. It should be non-hydroscopic.
6. Its physical and electrical properties must be less affected due to change in temperature.

So porcelain is used as the insulating material most commonly in overhead insulators [2]. The porcelain is nothing but aluminium silicate which mixed with plastic kaolin, feldspar and quartz to obtained final glazed and hard porcelain insulator material. As the surface is glazed, so that water should not be traced on it. Porcelain is also free from porosity, as the deterioration of its dielectric property is because of porosity. Also porcelain is free from any impurities and air bubble inside the material [2], [10].

In the overhead transmission line, the length of the composite insulator and the number of suspension insulator units depends not only on the voltage gradient but also the environment condition in case of the overhead transmission network. It also depends on properties of the materials used for insulator unit. A main problem in these insulators is the accumulation of a pollution layer that comes from the surrounding environment [4], [7]. The insulators of substations and overhead transmission lines, in desert areas which contain very fast sand particles are often due to sandstorms, hurricanes and cyclones. When the surrounding humidity of insulator string reaches a significant level due to rain, dew or fog formation on the polluted insulators by severe changes of temperature from night and day, as a result the conductivity of those pollutant layers is increased. So, a leakage current passes through the pollutant layers under this condition. It gives rise to heat, which results in the formation of dry bands on the insulator surface. Hence there will be the appearance of partial discharges on the insulator string surface. Where discharge activity on the surface of the insulator string is caused due to electric field. That electric field is more than the ionization level of the ambient air. This high electric field depends on the applied voltage, the type of materials used in the insulator string as well as the environmental conditions [1], [5], [7].

1.2 LITERATURE SURVEY

Extensive literature review of different journal paper related to insulator string voltage distribution and electric field distribution in different conditions, flashover of insulator and breakdown of insulator were studied. In 2006 S. IIhan, et al. [2] proposed the voltage distribution among the insulator units are not uniform in normal condition due to presence of stray capacitance. But in case of alternating and lightning impulse, potential distribution are same. Due to wind pressure the conductor swings towards the tower and the line metal clearance became critical. If the line clearance increases then the value of stray capacitance also increased and hence the potential distribution becomes more non-uniform. The voltage distribution improves in uniform contamination of the clean case for switching impulse voltages and power frequency voltages. But it has no effect for the lightning impulse voltages. Therefore it has more critical for contaminated insulator strings in lightning impulse voltages. In normal condition the insulator units are usually subjected to withstand higher electric stresses. To nullify the undesirable effects in case of randomly deposition of pollutants, it is better to be cleaned all units of string when replacing the failed units. In order to minimize the temporary outages all the units in the insulator string will be replaced by stronger fog-type units. Hence, replacement of lowermost and uppermost units with fog-type units can alleviate the problem. In 2007 V. T. Kontargyri, et al. [3] implemented how to use proper type of insulator which has given appropriate and required result in a very fast and economic way. The voltage distribution on a suspension type porcelain insulator string. Also the simulation results has been compared with experimental results. At the end it discussed the limitations of an electrostatic solution for the conducting and dielectric properties of the materials. In 2009 K. Siderakis, et al. [4] studied how to creepage distance correlated with the performance of the insulators in case of pollution condition especially in coastal regions. For condensation wetting, the whole creepage distance in addition with the protected parts were exposed to wetting. Hence it is required to determine the aerodynamic behaviour of insulator, amount of contamination accumulated and also the distribution of contamination along the leakage path. Therefore the more is the convoluted geometry of the insulator, the less is the cleaning effect of the wind and hence the surface conductivity formed is greater. So, the possibility of pollution flashover increased, where the creepage distance may be the same. In 2010 Ehsan Azordegan, et al. [5] proposed how to electromagnetic radiation signatures of a cracked and a polluted insulator string. Hence it was studied that, the characteristics of electromagnetic radiation for polluted and cracked insulator with respect to the negative and positive cycles. Also the electromagnetic radiations were captured by different receivers from the insulator strings. In 2013 Subba Reddy B, et al. [6] studied the field distribution and surface potential for single disc and insulator string for both in normal condition and in a string which has defective discs. How to enhance the electric stress across the first disc from the line end. Because it is required to improve the electric stress to prevent the flashover. According to the fault location on the string, it might be increased the percentage of electric stress across the first disc from the line end. Here it concludes that, the stress on the normal insulator string is depend on the location of the defective insulators of the insulator string. The effect of electric stress across normal insulator string when compared with defective insulator disc according to the location of defective disc. Hence it is helpful for power utilities while replacing the faulty discs in a string. In 2014 Ahmed el-Tayeb, et al. [7] concluded that, the potential distribution across the normal insulator string is both non-uniform and non-linear because of the presence of stray capacitance. But in the presence of pollution layer the potential distribution throughout the length of the insulator string makes linear. Due to the occurrence of pollution layer on the upper surface of insulator string is strongly modified the electric field distribution along the creep age path. Because of a homogenous pollution (i.e. the condition of uniform pollution) the insulator pin region of unit submits the highest stress, but the electric field is similar to that of clean insulator string. When the uniform contamination enhances the voltage distribution compared with that of clean one at the other hand the electric field distribution increases approximately six times when compared with clean and dry one. The linearization of potential distribution implies that, the higher voltages towards the centre of the insulator and the insulator surface is conducting. As a result the high field strengths arise near the sections with a small radius of curvature. Hence it may be initiate the corona. As compared to lower part of insulator with upper part of insulator for the same thickness and same conductivity of pollutant material has higher electric field.

1.3 MOTIVATION

The fact which motivated for accurate measurement of potential distribution in case of high voltage suspension insulator string under the influence of pollutant materials is, in nowadays there is a fast growing attention towards the development of electric arc across the polluted insulator units. A large number of experiments are conducted and so many studies have been published around the world to concern the occurrence of pollutant flashover. In spite of these significant efforts it has become evident that there is not a fully acceptable explanation of the pollution flashover mechanism and that is the reason why there is not still a general and efficient method in facing the problem. A few works have been reported in the voltage and electric field measurement of suspension insulator string accurately, simulation result comparison of normal one and polluted one suspension porcelain insulator string might not do properly, flashover and puncture of insulator due to non-uniform voltage and electric field distribution.

1.4 OBJECTIVE

The main objective of this research work is to measure the voltage distribution properly so that can avoid puncture and flashover of insulator string according to the required precautions. Because the voltage and electric field distributions are non-uniform on its units. Due to these non-uniformity insulator damage, electric discharge over the surface and lastly forced outage normally occurred in the pollutant regions. By using Ansys Maxwell software for simulation and design the more number of equations, time consumption and iteration points for convergence should be avoided. We can compare voltage distribution, electric field distribution and electric field vector distribution between normal and polluted insulator string. From that we can know withstanding and breakdown voltage of insulator disc. So that, we can take appropriate precaution for them.

1.5 THESIS ORGANIZATION

The outline of the work is as follows:

- **Chapter 1** presents the background for this thesis research, having introduction with a comprehensive literature review in related area.
- **Chapter 2** presents the types of pollution, design of single disc porcelain insulator both in normal and polluted condition, theoretically calculation of voltage distribution in insulator string and effects of electric field distribution.
- **Chapter 3** presents the simulation results of voltage distribution, electric field and electric field vector distribution along with discussions for various conditions of insulator string and also graphical studies of creepage voltage in various environmental conditions, voltage gradient among the insulator discs and electric field along the leakage distance in all the environment conditions.
- **Chapter 4** concludes the work and proposes scope for future work in this domain.

CHAPTER-2

THEORETICAL STUDIES OF SUSPENSION INSULATOR

2.1 INTRODUCTION

Among all the types of insulator suspension insulator plays a vital role in high voltage transmission lines. Because it is economical with respect to size and weight of the other types of insulator. In case of suspension insulator string formation is possible by connecting more number of insulators in series. By doing this replacement of damaged insulator unit is become easier. The main focus in all types insulators are voltage and electric field distribution. Because these are responsible for premature aging of insulator, audible noise and also for partial discharge on the insulator surface. Electric field distribution and voltage distribution are mainly depends on applied voltage, properties of materials used in insulator and surrounding or environmental condition (contamination type and level) [3], [8].

2.2 TYPE OF POLLUTION

The insulators on transmission lines are normally subject to the deposition of pollutant materials on the insulator surface by the environment. As the nature of the pollutants deposition is mostly affected by nature of the environment. Mainly, the nature of the deposition of pollutant on the surface of the insulator are two types like uniformly deposited pollutants and non-uniformly deposited pollutants. Similarly, the types of pollution are mainly of two types (according to the nature of pollutant materials) like coastal pollution and industrial pollution [4].

Coastal Pollution:

The insulators those are located in coastal regions especially contaminated by soluble contaminants, mostly NaCl (Sodium chloride). The salt spray from the sea or wind driven salt laden solid material such as sand collects on the insulator surface. These layers become conducting during periods of high humidity and fog. Sodium chloride is the main constituent of this type of pollution. The flashover can occur as long as the salts are soluble enough to form a conducting layer on the insulator surface, irrespective of the contaminant nature [5].

Industrial Pollution:

Substations and power lines near industrial complexes are subjects to the stack emissions from nearby plants. These materials are usually dry when deposited; they may then become conducting when wetted. The materials will absorb moisture to different degrees and apart from salts, acids are also deposited on the insulator. Industrial pollutions which occurred mainly in paper and cement industry areas are especially contaminated by a significant amount of non-soluble contaminants. Rather than all of the above some of the contaminants are occurred due to calcium chloride, carbon and cement dust [5].

Many dedicated computer packages are much helpful for design and simulation of insulator. As they are making a digital model for any insulator and their performance by the help of computer simulation. The design and computer simulation that is used here depends on FEM (Finite Element Method) of Ansys Maxwell package. Preference of this computer based design and simulation is only because of more precise results will get in very less time and in more economical way [6].

2.3 INSULATOR UNDER STUDY

The porcelain insulator is widely used for 132 kV, 220 kV and 500 kV transmission lines. Fig. 1 shows the single unit of porcelain insulator which used in this study for normal condition. Fig. 2 shows the single unit of porcelain insulator which used in this study for polluted condition. Normally a thickness of 0.03mm to 0.09mm pollutant materials are distributed either uniformly or non-uniformly on the insulator surface. The insulator cap and the insulator pin are made from steel and they are embedded in bonding material (cement layer) with a relative permittivity of 14 and a conductivity of $10^{-13}\, S/m$ in order to fix with porcelain shell and the shell is made of porcelain which has a relative permittivity of 6 with a conductivity of $2\times10^{-13}\, S/m$. In polluted condition for coastal pollution, the pollutant material is NaCl whereas for industrial pollution, the pollutant material include calcium chloride, carbon and cement dust. For coastal pollutant the relative permittivity of 4.5 and conductivity of $70\mu S/m$ whereas for industrial pollutant the relative permittivity of 2 and conductivity of $30\mu S/m$. The pollutant conductivity may varies according to the thickness of the pollutant materials deposited on the surface of the insulator. The total insulator string consists of 7 units for 132 kV transmission line [4], [11].

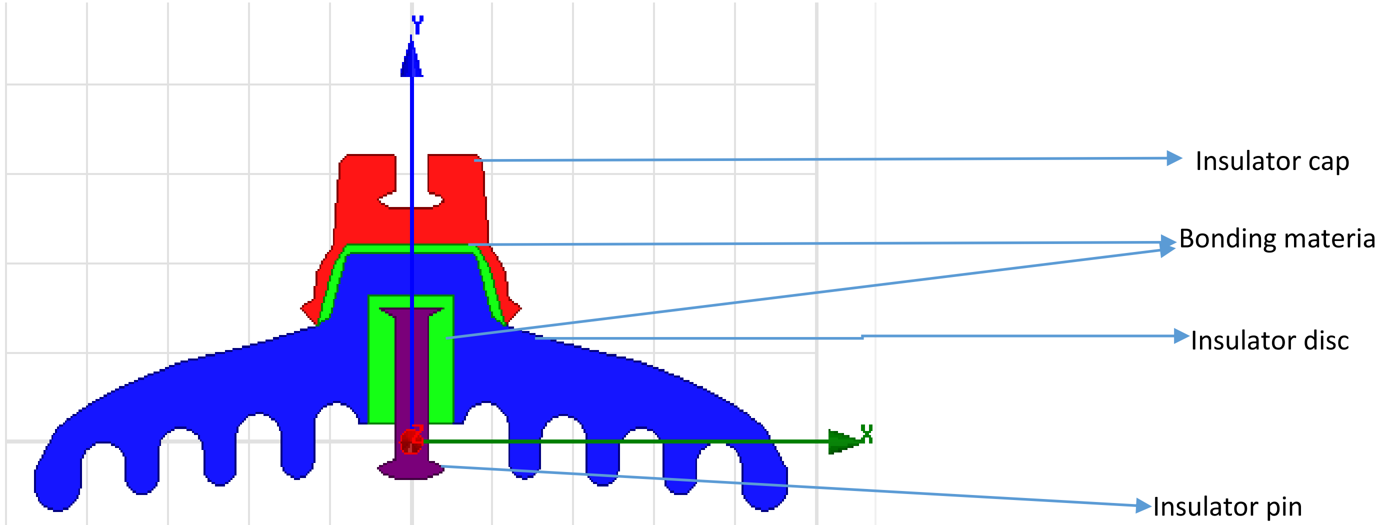


Fig. 1: Various parts of single disc insulator in normal condition

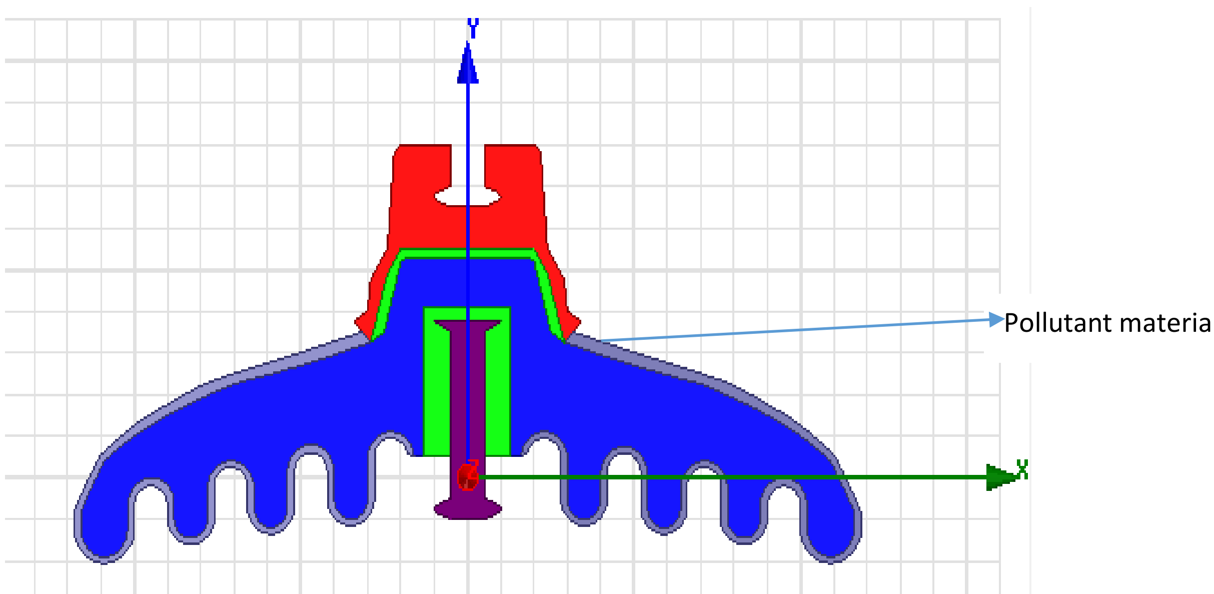


Fig. 2: Various parts of single disc insulator in pollution condition

2.4 THEORETICALLY VOLTAGE DISTRIBUTION

The voltage distribution in an insulator string is not uniform in normal or clean condition. The non-uniformity in the potential distribution due to the presence of stray capacitance. The voltage near to the power conductor is attend the maximum value whereas the voltage near to tower end is minimum. To maintain the uniformity in the voltage distribution various techniques are adopted, such as using longer length of cross arm, using capacitance grading, using static shielding or guard ring.

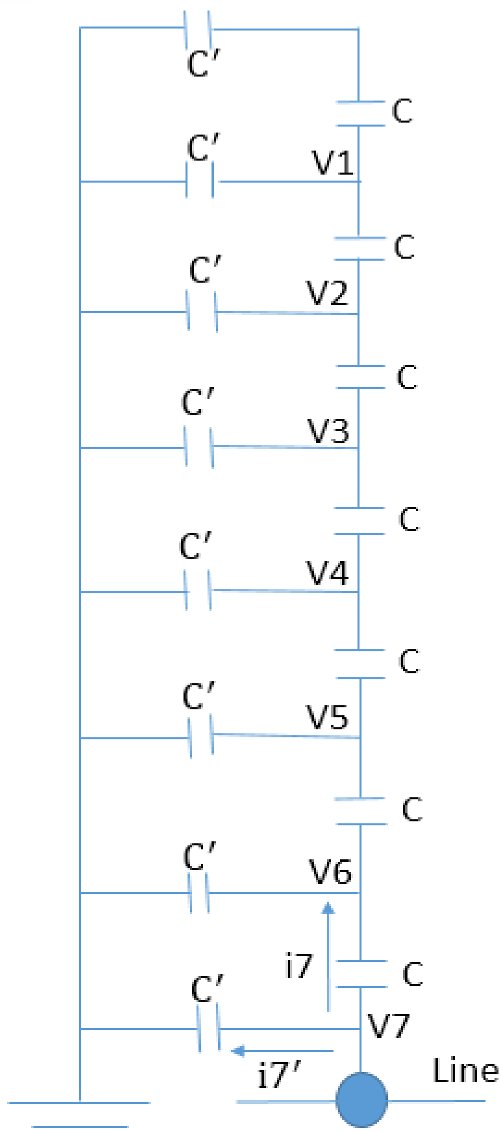


Fig. 3: Equivalent circuit of an insulator string with seven units in a 132 kv line in normal condition

Fig. 3 indicates equivalent circuit of an insulator string with seven units in a 132 kV line [3]. But when the pollutant materials cover the insulator surface, then it considerably changes the voltage distribution and electric field distribution across the specified insulator units. Pollution is normally replicated by a high resistance attached across the self-capacitance of each unit. This resistance value depends upon pollution conductivity, diameter of insulator along with arc length on insulator's surface which can be considered equal to creepage distance and cross section of pollution on insulator surface. This resistance value may be ranged from several MΩ to tenths of kΩ. This will change the capacitance ratio (self-capacitance to shunt-capacitance ratio), which has mainly affected the voltage distribution in insulator string. The deposition of pollutants on the surface of the insulator became conductive and provide a path across the insulator for leakage current. When the temperature increases it forms a dry band on the insulator surface which increases the voltage gradient until arcing occurs across the bands [11].

By solving KVL and KCL equations for equivalent circuit of insulator string, each unit voltage can be calculated as follows;

$$I_{n+1}=\frac{\Delta V_{n+1}}{X_c} = \mathrm{C}.\,\omega.\,\Delta V_{n+1} \tag{1}$$

$where$,C is capacitance between each insulator unit and line conductor or line capacitance, C' is capacitance between each unit and ground or stray capacitance, I_{n+1}(A) is current flow in the $(n+1)^{th}$ unit due to current inn^{th} unit line capacitance and that of stray capacitance, ΔV_{n+1}(V) is voltage across $(n+1)^{th}$unit due ton^{th}unit line capacitance voltage and that of stray capacitance,X_c(Ω) is capacitive reactance of line capacitance, $\omega(rad/sec)$ is power frequency.
The current flow in the n^{th} unit of stray capacitance,I'_n(A), is calculated as follows

$$I'_n= \frac{V_{n+1}}{X'_c} = C'.\omega.V_{n+1} \tag{2}$$

$where, X'_c$(Ω) is the capacitive reactance of stray capacitance, V_{n+1}(V) is the voltage of $(n+1)^{th}$unit only due to line capacitance.
The current in the n^{th} unit line capacitance,$I_n(A)$, is calculated as follows

$$I_n= \mathrm{C}.\omega.\Delta V_n \tag{3}$$

where, ΔV_n(V) is the voltage across n^{th} unit due to both line capacitance voltage and that of stray capacitance.

The current flow in the $(n+1)^{th}$ unit due to current in n^{th} unit line capacitance and that of stray capacitance, I_{n+1}(A), is calculated as follows

$$I_{n+1} = I_n + I'_n \tag{4}$$

Capacitance ratio or de-multiplication factor, m, is given as

$$m = \frac{C}{C'} \tag{5}$$

According to the above equations (1) - (5):

$$\mathrm{C}.\omega.\Delta V_{n+1} = \mathrm{C}.\omega.\Delta V_n + \frac{C}{m}\omega.V_{n+1} \tag{6}$$

$$\Delta V_{n+1} = \Delta V_n + \frac{V_{n+1}}{m} \tag{7}$$

Then:

$$V_{n+1} = V_n + \Delta V_n \tag{8}$$

$$\Delta V_0 = V_1 \tag{9}$$

$$\Delta V_1 = (1 + \frac{1}{m})\, \Delta V_0 \tag{10}$$

Where, ΔV_0(V) is the voltage across first unit from tower side, ΔV_1(V) is the voltage across second unit from tower side, ΔV_2(V) is the voltage across third unit from tower side.

$$\Delta V_2 = (1 + \frac{3}{m} + \frac{1}{m^2})\, \Delta V_0 \tag{11}$$

And so on.

In the above expression when the capacitance ratio (m) increases to higher value, then the potential distribution across the various discs of the insulator string tends to be more homogenous.

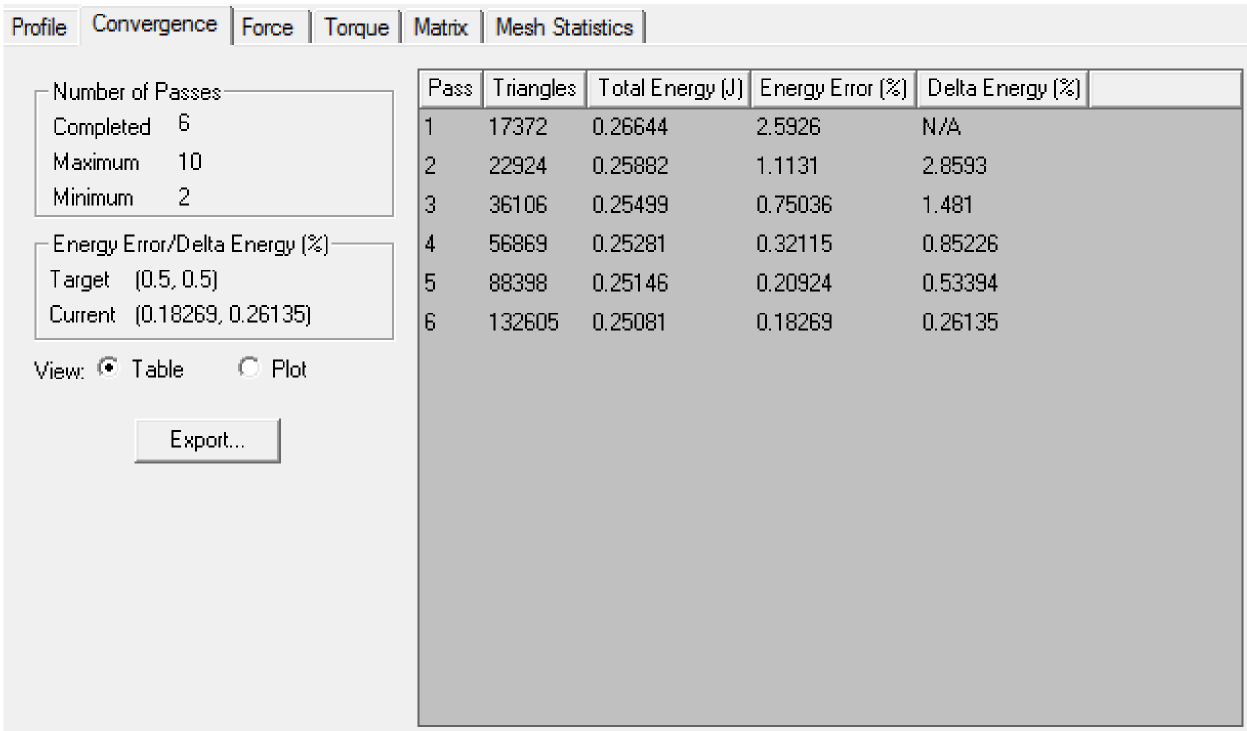
2.5 EFFECTS OF ELECTRIC FIELD DISTRIBUTION

For the design of the insulator, calculation of the electric field and potential distribution across the high voltage insulator is more essential. The electric field in high levels are mostly responsible for partial discharge, audible noise and premature aging of insulator. As the flashover propagation depends on electric field, so a descent electric field distribution is essential for insulator string. The flashover is nothing but an arc formation between the conducting parts and over the insulator surface, as the result of breakdown of dielectric strength of surrounding air. Due to the effect of pollution layers for calculation of electric field and voltage distributions around and inside the insulator unit, the insulator pin of first unit (line end unit) is stressed by 132 kV AC voltage whereas in the insulator cap of the 7^{th} unit is grounded. The accuracy of the calculation is increased by increasing the number of meshes [4], [13].

CHAPTER-3

RESULTS AND DISCUSSIONS

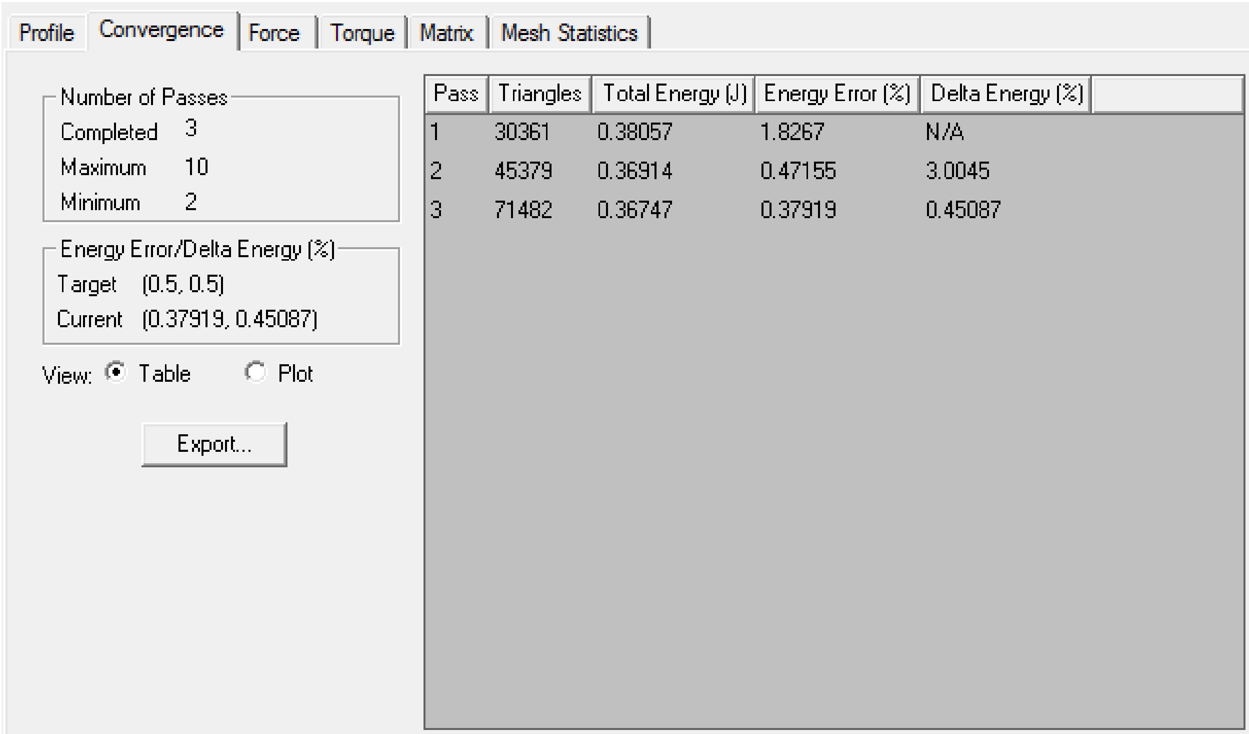
The symmetry of the insulator assembly is exploited when creating the finite element model, resulting in axis-symmetric two dimensional problems. The model is generated with the help of key points later joined and designed by poly lines and then forming 2-D area model. In this designed Maxwell 15.0 software is used. This model is designed with the help of Maxwell software where the solution type is electrostatic. The percentage of error is fixed below 0.5%, the refinement per pass is 50%, the non-linear residual is fixed below 0.0001 and five iteration points are taken in case of all the models. The applied model consists of 6 parts for normal insulator string and 7 parts for polluted insulator string. The 6 parts are cap (ductile iron), pin (forged iron), disc (porcelain), bonding material (cement), surrounding air and 7th part is pollutant material (salt, pollutant dust from cement or paper industry). The thickness of pollutant material is 0.07mm and it is uniformly polluted. Here two pollution cases are taken, such as coastal pollutant and industrial pollutant. In case of coastal pollution the pollutant material is salt where as in case of industrial pollution the pollutant material is industrial dust. The applied polluted models are uniformly polluted. The voltage distribution and electric field distribution are different according to the pollutant material and their properties in case of pollutant insulator string. Between the applied pollutant models coastal pollutant material has more permittivity and conductivity than that of industrial pollutant material. All the applied models and simulations are done under a standard temperature that is at 23 degree Celsius and also at a standard atmospheric pressure.



Pass	Triangles	Total Energy (J)	Energy Error (%)	Delta Energy (%)
1	17372	0.26644	2.5926	N/A
2	22924	0.25882	1.1131	2.8593
3	36106	0.25499	0.75036	1.481
4	56869	0.25281	0.32115	0.85226
5	88398	0.25146	0.20924	0.53394
6	132605	0.25081	0.18269	0.26135

Table 1: Convergence criteria for 132 kV insulator string in normal condition

Here the Table 1 shows the total convergence criteria in case of 132 kV insulator string in normal condition. Whereas Table 2 shows the total convergence criteria in case of 132 kV insulator string in normal condition. In both the cases for convergence the energy error and delta energy error is fixed below 0.5%. Convergence in case of normal condition takes more times than that of in case of polluted condition. Because the number of passes and number of triangles in case of normal condition is more than that of polluted condition. The convergence criteria meet in six passes in case of normal condition in which the maximum number of passes for convergence is ten. Whereas in case of polluted condition the convergence criteria meet in three passes. It is observed that, more number triangles are formed in case of normal condition , as the specified region for convergence in case of normal condition is less than that of in case of polluted condition. Finally, from Table 1 the convergence is achieved when energy error is 0.18269% and delta energy is 0.26135%. Whereas from Table 2 (polluted condition) it is 0.37919% and 0.45087% respectively.



Pass	Triangles	Total Energy (J)	Energy Error (%)	Delta Energy (%)
1	30361	0.38057	1.8267	N/A
2	45379	0.36914	0.47155	3.0045
3	71482	0.36747	0.37919	0.45087

Table 2: Convergence criteria for 132 kV insulator string in polluted condition

To achieve required level of accuracy in result, the mesh needs to be refined in areas where fields are of interest or the field gradients are high and adaptive meshing provides automated mesh refinement capability which is depend on desired energy error in simulation. It is only available in case of static solvers. Fig. 4 shows mesh analysis of 132 kV insulator string in normal condition. Whereas Fig. 5 shows mesh analysis of 132 kV insulator string in polluted condition. In mesh analysis the total specified region is divided into some triangles and it converges according to the triangles. In case of polluted condition the specified region is larger than that of in case of normal condition. As the electric field distribution is depend on the convergence region or mesh region, so electric field distribution is higher in case of polluted condition than that of normal condition.

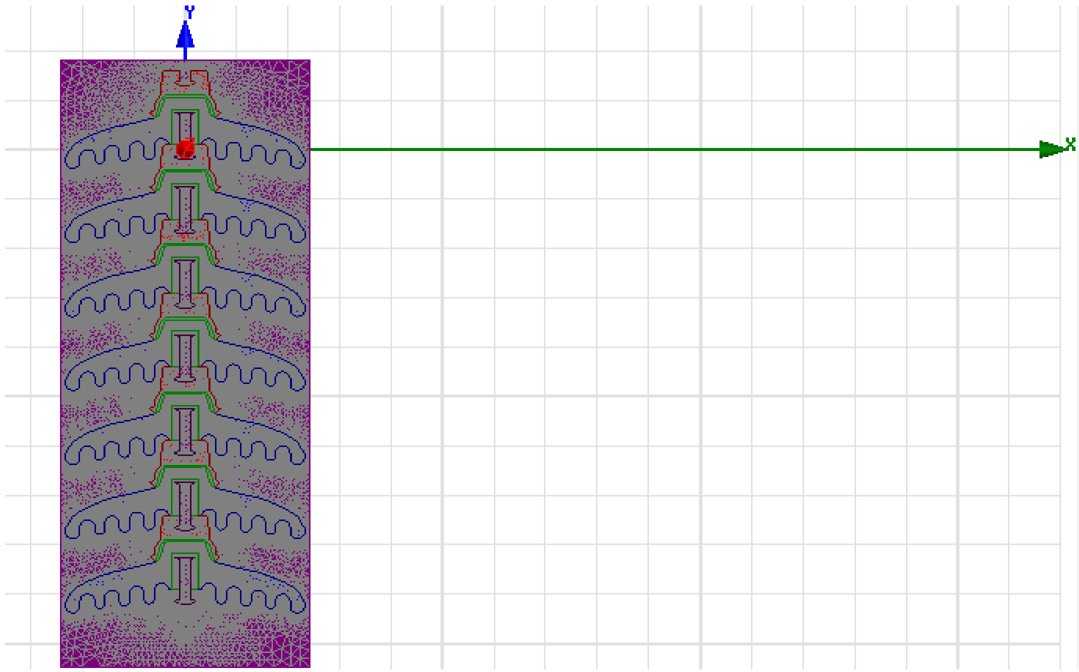


Fig. 4: Mesh analysis of 132 kV insulator string in normal condition

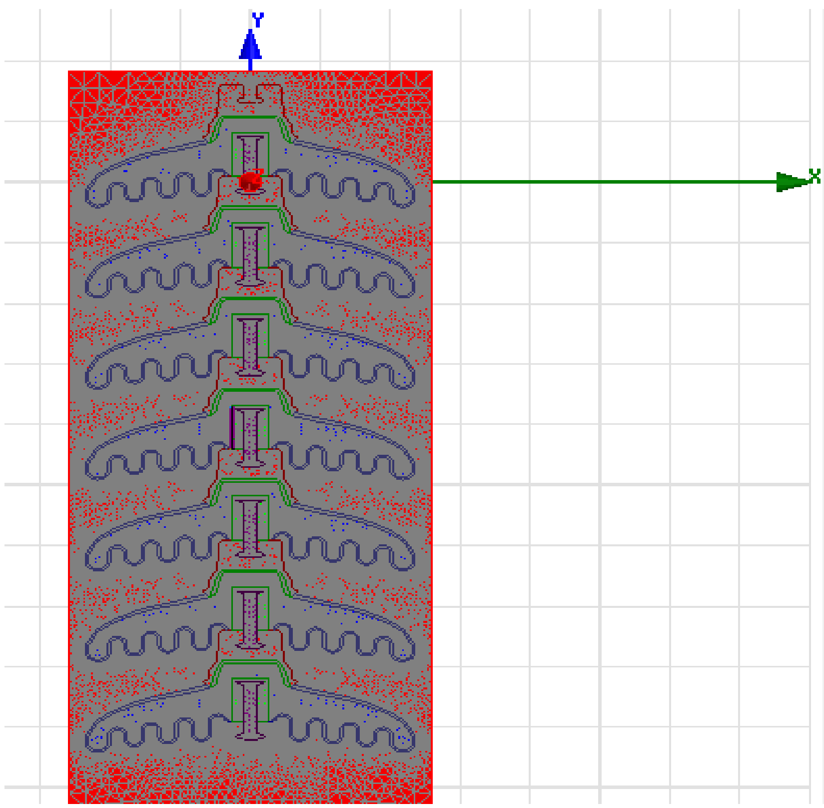


Fig. 5: Mesh analysis of 132 kV insulator string in polluted condition

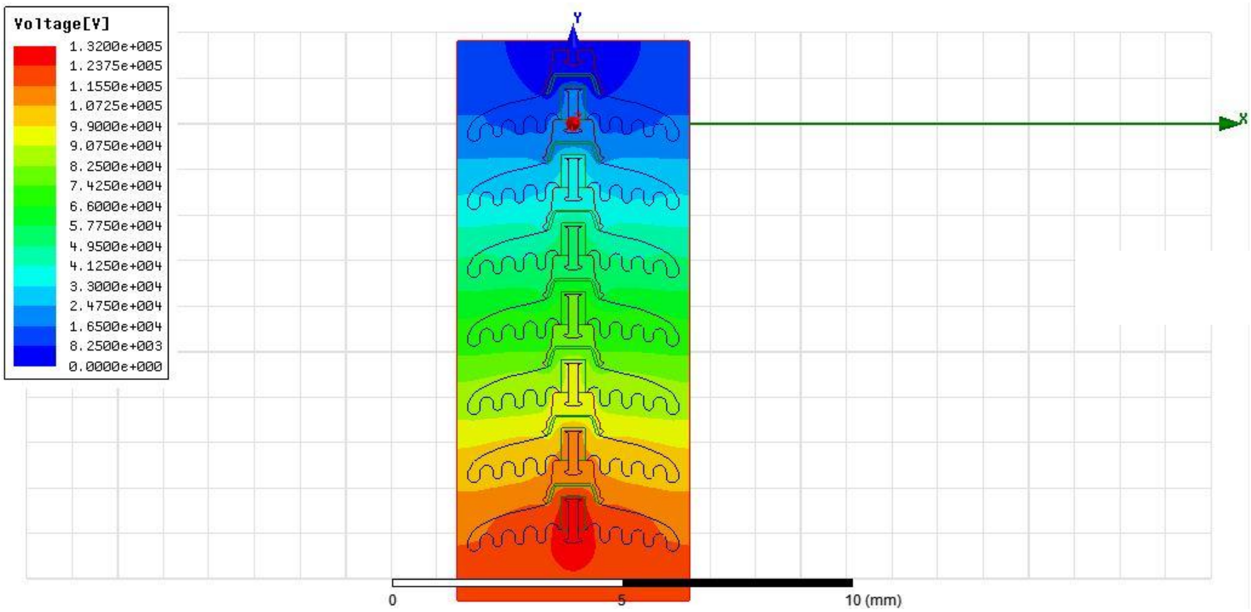


Fig. 6: Voltage distribution of 132 kV insulator string in normal condition

Firstly, calculation is performed for the case of normal condition (clean insulator string). Fig. 6 indicates the simulation result for voltage distribution in 7 units clean insulator string where the supply voltage is 132 kV. It concluded that the voltage distribution is non-linear and non-uniform along the surface of insulator string because of stray capacitances. The maximum voltage is achieved at the insulator pin of the line end unit whereas the minimum voltage is achieved at the insulator cap of the 7^{th}unit in the insulator string. Therefore at high voltages corona rings are connected with the composite insulators. The voltage between 1^{st}unit and7^{th}unit of the insulator string is distributed according to the capacitance and stray capacitance to the line and to the ground.

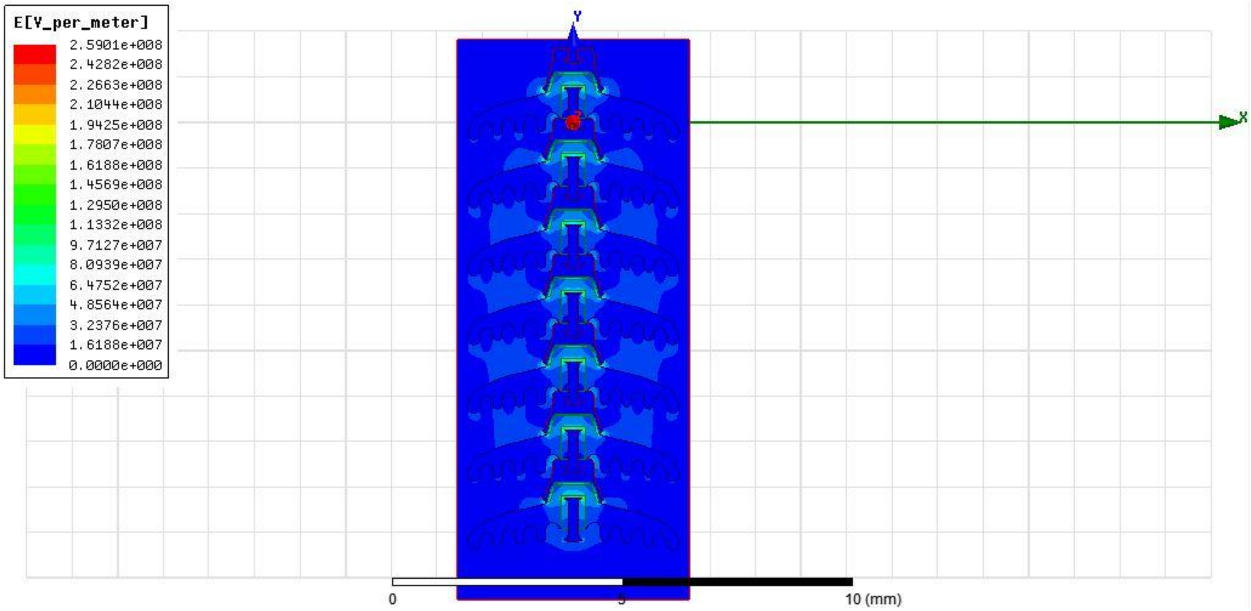


Fig. 7: Electric field distribution of 132 kV insulator string in normal condition

Fig. 7 shows the electric field distribution of 7 units insulator string under normal condition where the applied voltage is 132 kV. It is indicate that the electric field intensity is higher at those points which are closer to energized end (insulator pin) than those points which are closer to the grounded end (insulator cap). Also it is observed that, the magnitude of electric field has higher values at the junction of (air-cap-porcelain), the junction of (air-pin-cement-porcelain), near the section of a small radius of curvature and live-end-fitting.

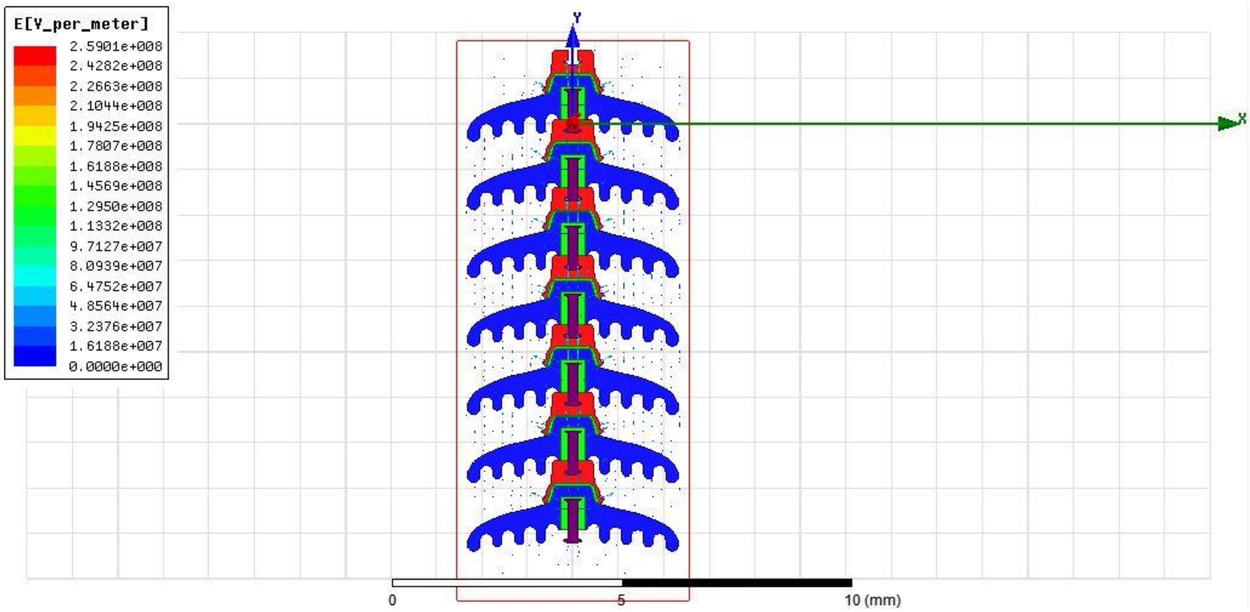


Fig. 8: Electric field vector distribution of 132 kV insulator string in normal condition

Fig. 8 shows the electric field vector distribution of 7 units based insulator string where the applied voltage is 132 kV in normal condition. The electric field vectors are stronger at the junction of insulator pin-cement-porcelain. The electric field vectors are scattered throughout the specified region.

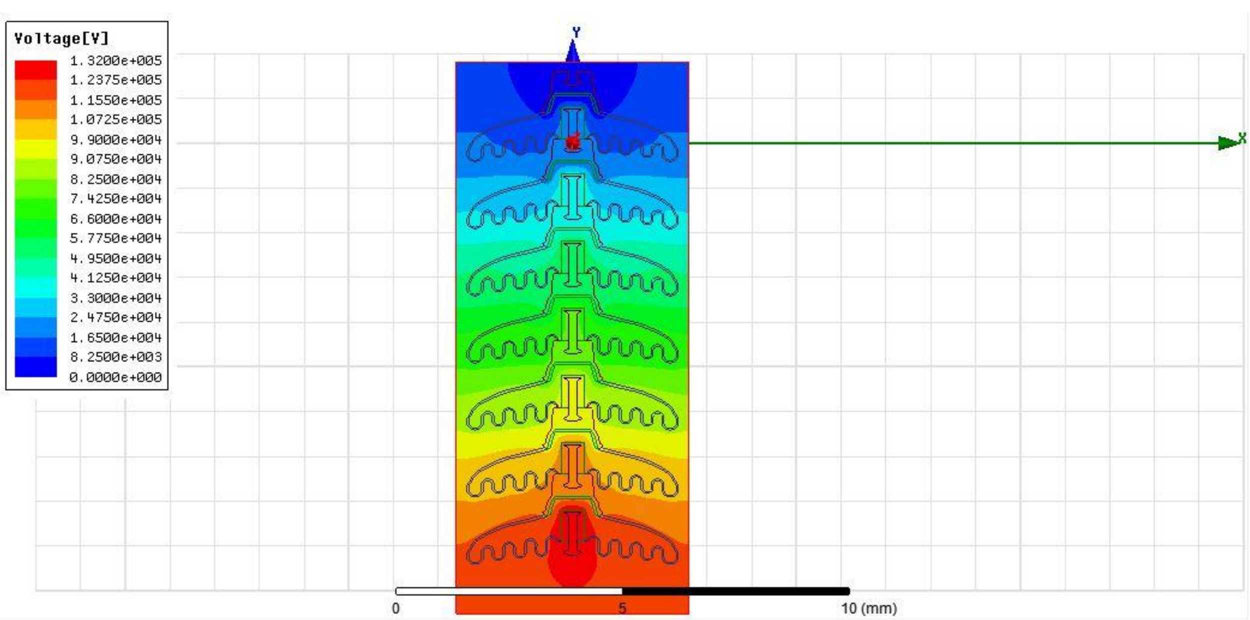


Fig. 9: Voltage distribution of 132 kV insulator string in coastal pollutant condition

For the outdoor high voltage transmission line applications, the insulator strings are exposed not only to the atmosphere but also to the different type of pollutant conditions. Fig. 9 shows the voltage distribution of insulator string in coastal pollutant condition where the applied voltage is 132 kV. The voltage distributions as well as the electric field distributions throughout the insulator string in clean or normal condition are quite different from those with a uniform pollutant on the surface of the insulator. The potential distribution is observed to be minimum at the insulator cap of the 7^{th} unit and maximum at the insulator pin of the1^{st} unit. The voltage distribution between the insulator cap of the 7^{th} unit and the insulator pin of the1^{st} unit of the string is found to be uniform. It also noticed that, the potential distribution across the specified region is tends to be linear.

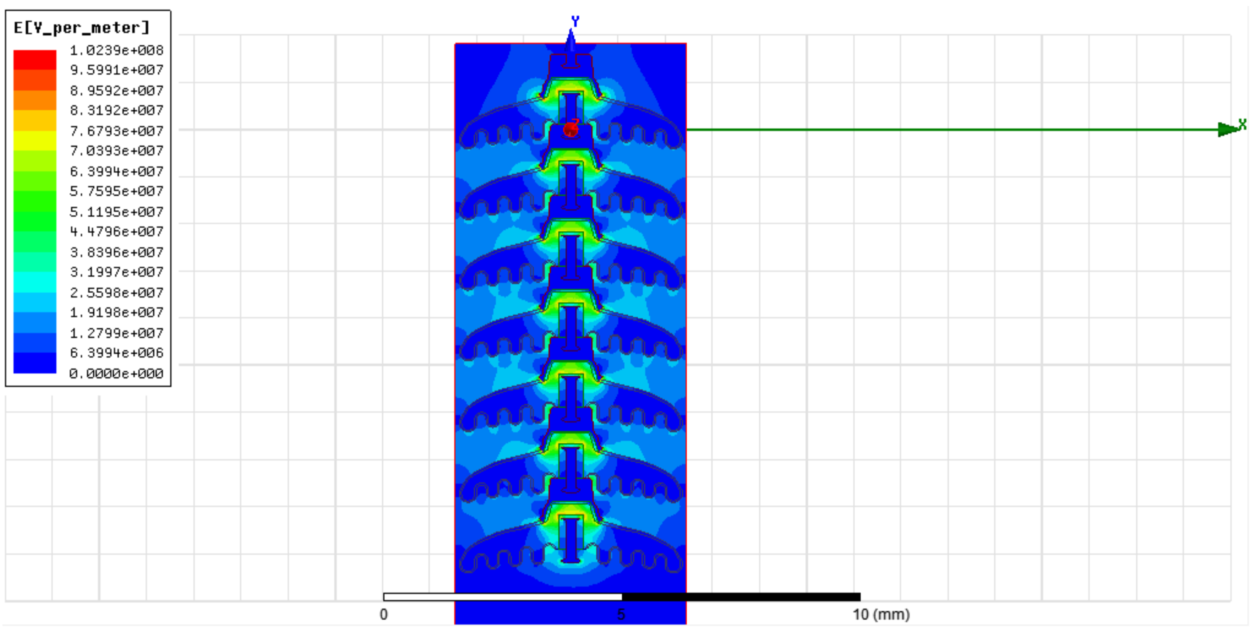


Fig. 10: Electric field distribution of 132 kV insulator string in coastal pollutant condition

Whereas Fig. 10 indicates the electric field distribution of insulator string in coastal pollutant condition for 132 kV. Here it is concluded that the electric field is higher in those areas which are closed to the energized end than those areas which are closed to the grounded end. The electric field has attended a strength magnitude with high values at the junction of (air-insulator cap-porcelain) and (air-insulator pin-cement-porcelain) and at the live-end-fitting.

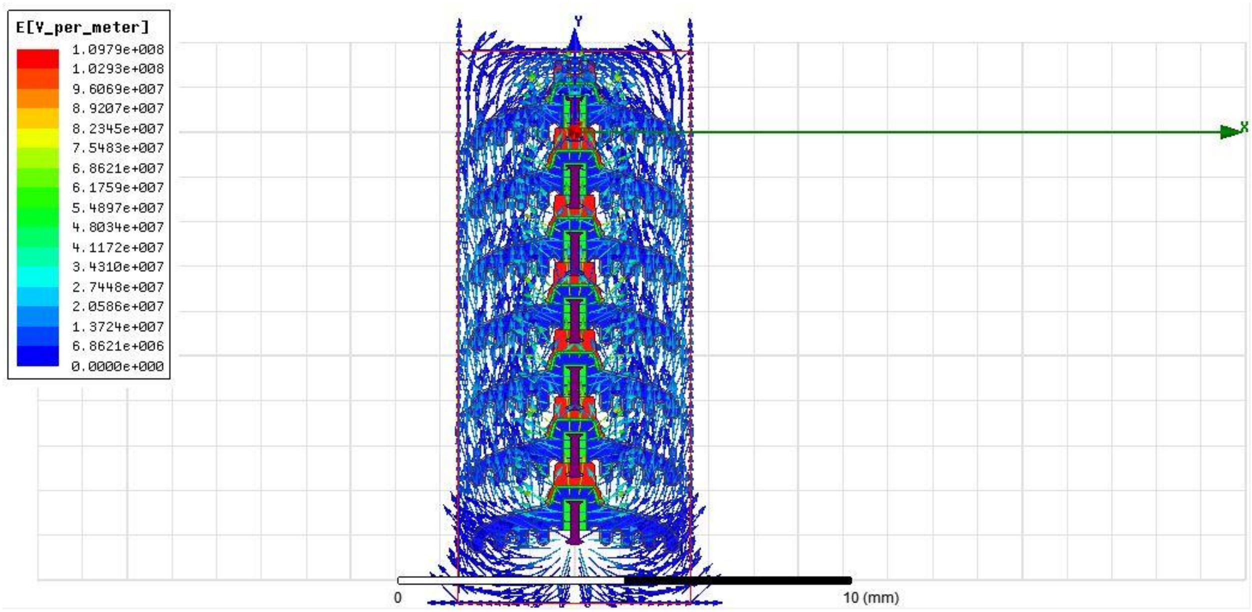


Fig. 11: Electric field vector distribution of 132 kV insulator string in coastal pollutant condition

Fig. 11 shows electric field vector distribution of 132 kV insulator string in case of coastal pollutant. As electric field vector distribution mainly depends upon conductivity, so it has more density in this case. The electric field vectors are going from more energized region to less energized region (from insulator pin of the 1^{st}unit to insulator cap of the 7^{th}unit).

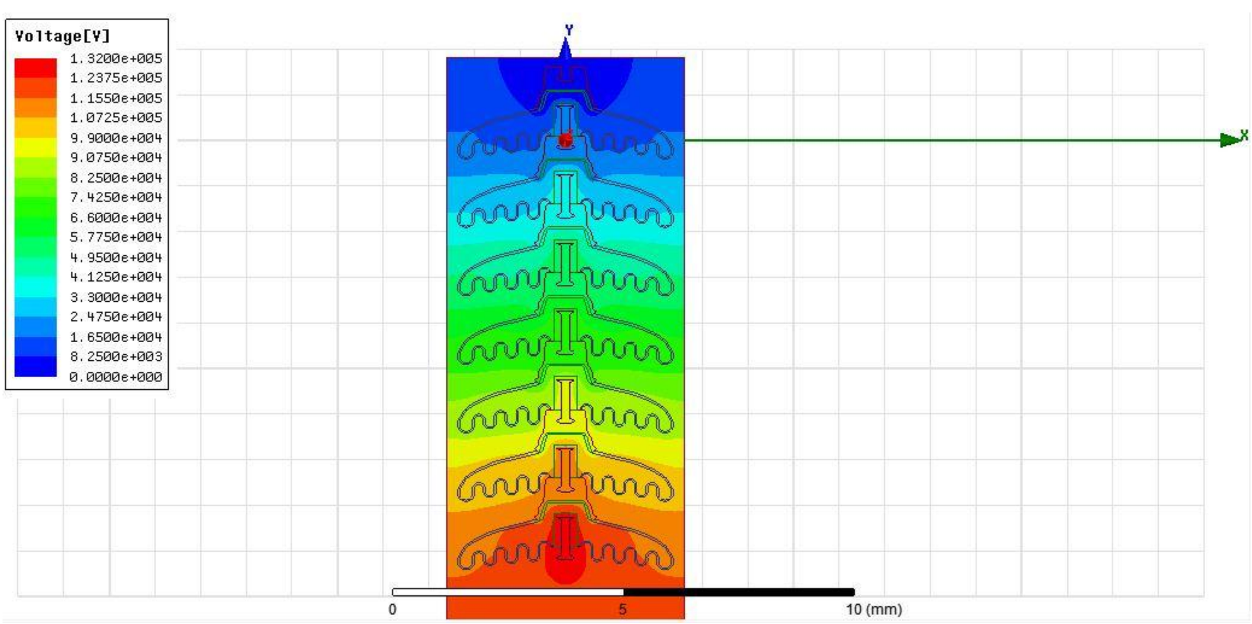


Fig. 12: Voltage distribution of 132 kV insulator string in industrial pollutant condition

Fig. 12 shows the potential distribution in case of 132 kV insulator string where the insulator surface is uniformly polluted by industrial pollutant. It is observed that the insulator pin of 1^{st}unit has maximum value whereas the insulator cap of 7^{th}unit has minimum value and the voltage between them is varied very firstly throughout the length. But the voltage distribution across the specified area is approximately linear and uniform.

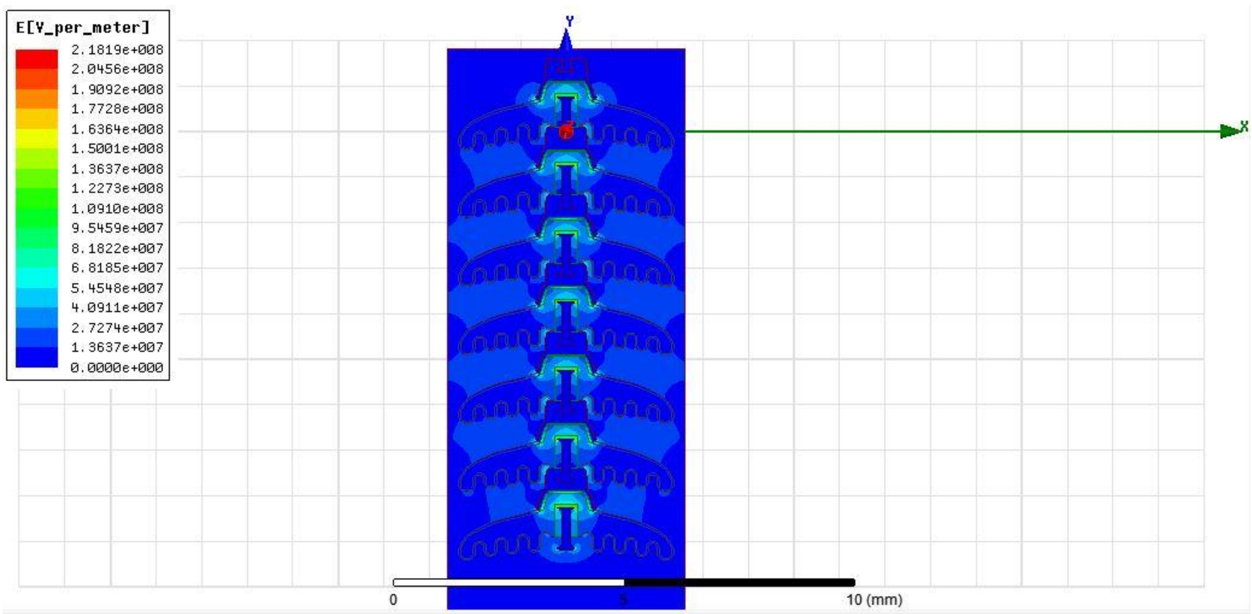


Fig. 13: Electric field distribution of 132 kV insulator string in industrial pollutant condition

The Fig. 13 indicates the electric field distribution across the 132 kV insulator string when the surface of the insulator disc is polluted by industrial pollutants. It is observed that the electric field intensity is higher at the energized end (insulator pin) than the electric field intensity at the grounded end (insulator cap). The electric field has indicated its highest value as compare to its all other values throughout the specified region is at the junction of air-insulator cap-porcelain region. The other electric field high values are appeared at the junction of the air-insulator pin-cement-porcelain region, near the sections with a smaller radius of curvature and live-end-fitting.

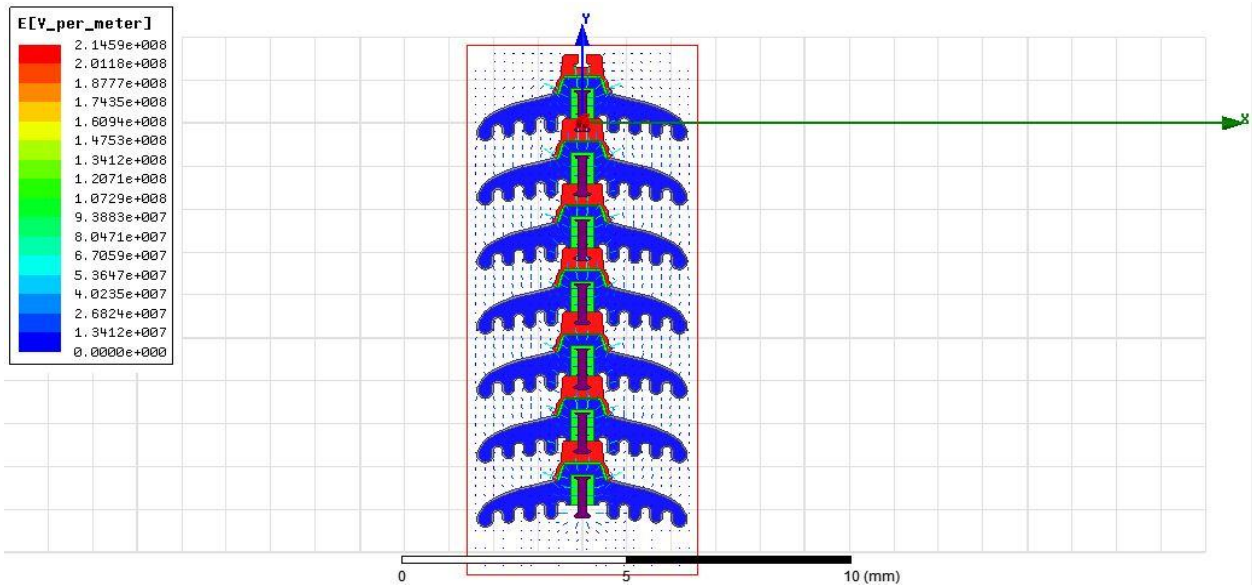


Fig. 14: Electric field vector distribution of 132 kV insulator string in industrial pollutant condition

The Fig. 14 shows electric field vector distribution of 132 kV insulator string when the surface of the insulator is polluted by uniformly covered industrial pollutant. It is observed that the electric field vectors are attended its highest strength at the junction of insulator pin-cement-porcelain when compared the strength of that with other regions in the specified area.

DISCUSSION

From the above results of voltage distribution, it is observed that the voltage distribution in case of coastal pollution is more linear and more uniform than the others. The voltage distribution in case of industrial pollution changes very firstly when compared to the other two cases. The voltage distribution in case of clean insulator string (normal condition) is non-linear as well as non-uniform. So from linearity and uniformity point of view voltage distribution in case of industrial pollution stands in the middle.

From the above results of electric field distribution, it is concluded that the electric field magnitude is maximum in case of coastal pollution when it compared with other cases. In all the cases the maximum values are observed at the junction of insulator pin-cement-porcelain region. The electric field magnitude distribution is least in case of clean or normal condition insulator string and in case of industrial pollution it is moderate. Electric field increases with the increase in the polluted layer conductivity in case of pollutant conditions.

From the above results of electric field vector distribution, it is observed that the density of electric field vector is maximum in case of coastal pollution. As density of electric field vector depends on conductivity of material and in case of coastal pollution, the pollutant material higher conductivity than that of industrial pollutant. The electric field vector distribution density in the specified region is minimum in case of clean or normal condition insulator string. In all the cases the electric field vector density is more at the energized end (1^{st}unit of the insulator pin).

GRAPHICAL STUDY

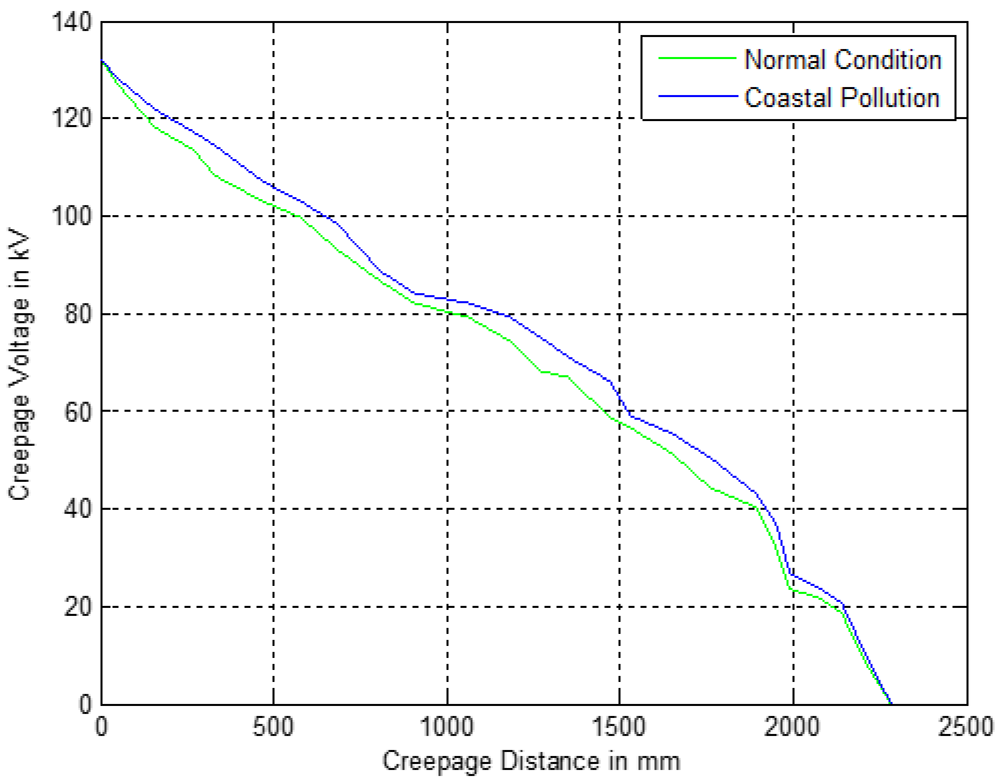


Fig. 15: Creepage voltage distribution of insulator string in normal and coastal pollution conditions

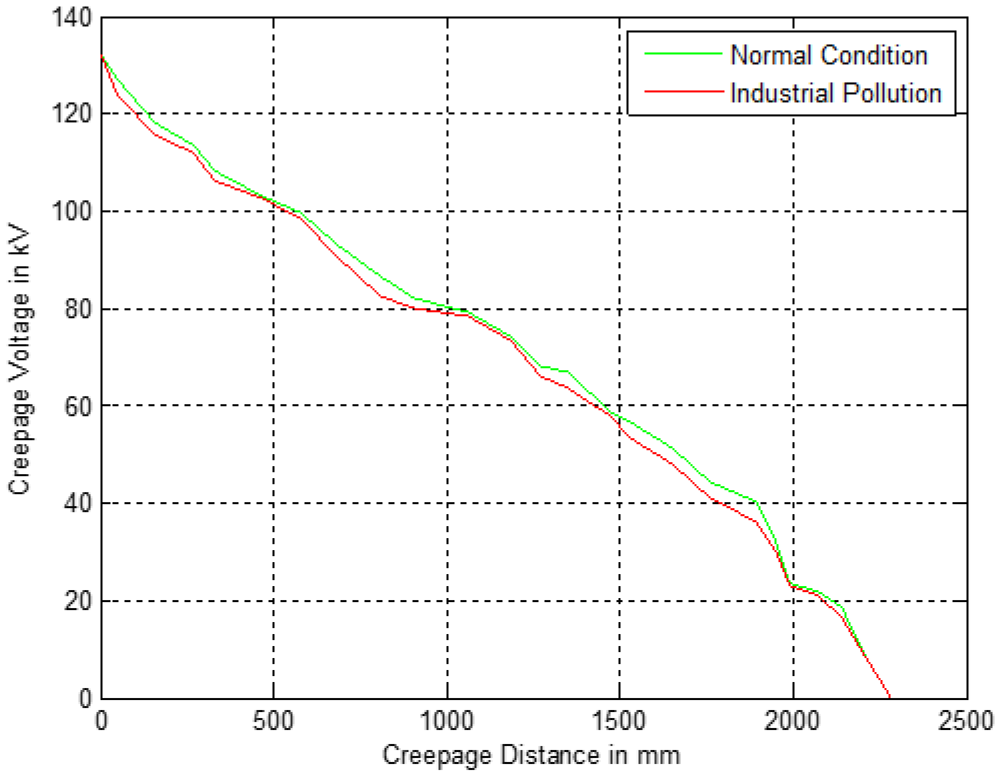


Fig. 16: Creepage voltage distribution of insulator string in normal and industrial pollution conditions

Creepage distance is nothing but a shortest distance the two electrodes which is along the surface of the insulator disc and that of the voltage is called creepage voltage.Fig. 15 shows the graphical comparison of creepage voltage vs creepage distance between normal and coastal polluted condition. Creepage distance must be increase in highly polluted sea salt areas. So, the creepage voltage is higher in case of coastal pollution than that of in normal condition for the same creepage distance. An average of 6.2% difference is observed when creepage voltage of coastal pollutant condition compare with that of normal one. Fig. 16 shows the graphical comparison of creepage voltage vs creepage distance between normal condition and industrial pollution condition. The creepage voltage in case of industrial pollution lies below that of in case of normal condition. An average of -3.5% difference is observed when creepage voltage of industrial pollutant condition compare with that of normal condition.

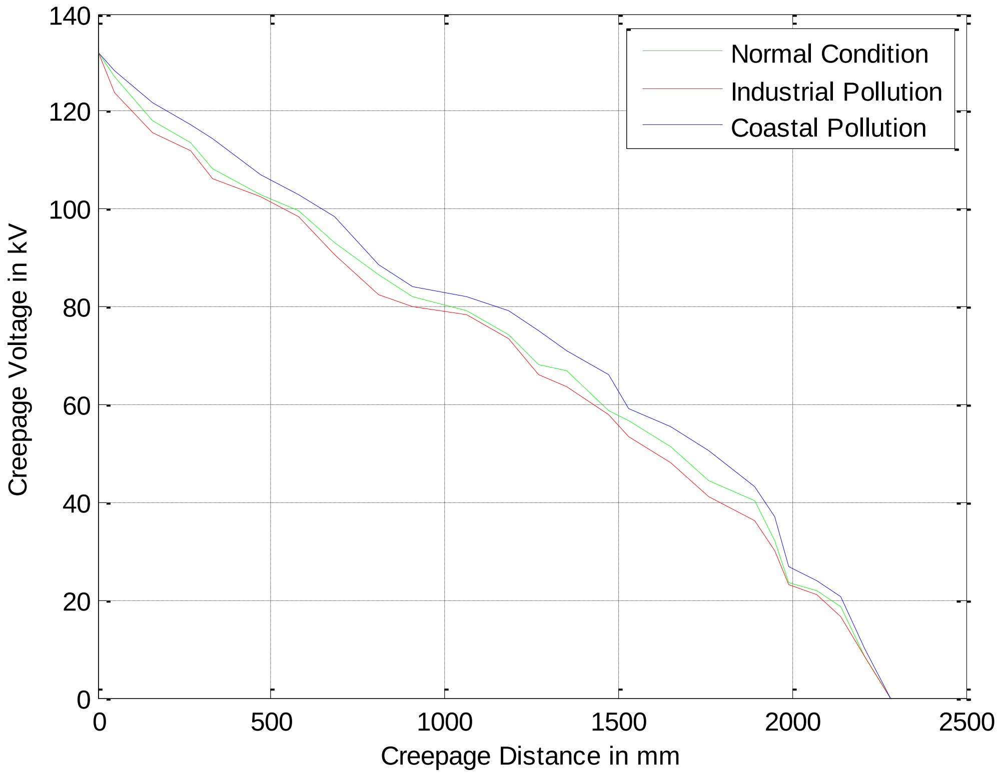


Fig. 17: Creepage voltage distribution in all the environmental conditions

Fig. 17 shows the graphical comparison of creepage voltage vs creepage distance between all the environmental conditions (normal condition, coastal pollutant condition and industrial pollutant condition). Creepage distance is more important in design point of view. Because it is protected from tracking and for localized deterioration on the insulating material of its surface is produced a partially conducting root. It is observed that the creepage voltage in case of coastal pollution condition is more than that of other two conditions and among all the conditions industrial pollutant condition has least value of creepage voltage. An average of 9.7% difference is observed when creepage voltage of coastal pollutant condition compare with that of industrial pollutant condition.

Fig. 18 gives the graphical comparison 0f voltage gradient along the discs of the insulator string in all the environment conditions (in normal, coastal polluted and industrial polluted conditions). By comparison it is concluded that the voltage gradient is more uniform and linear in case of coastal pollutant condition and least uniform and linear in normal condition. It is due to the increase in line capacitance value because of high permittivity in case of coastal polluted condition. So, that the capacitance ratio is increased (line capacitance divided by stray capacitance).

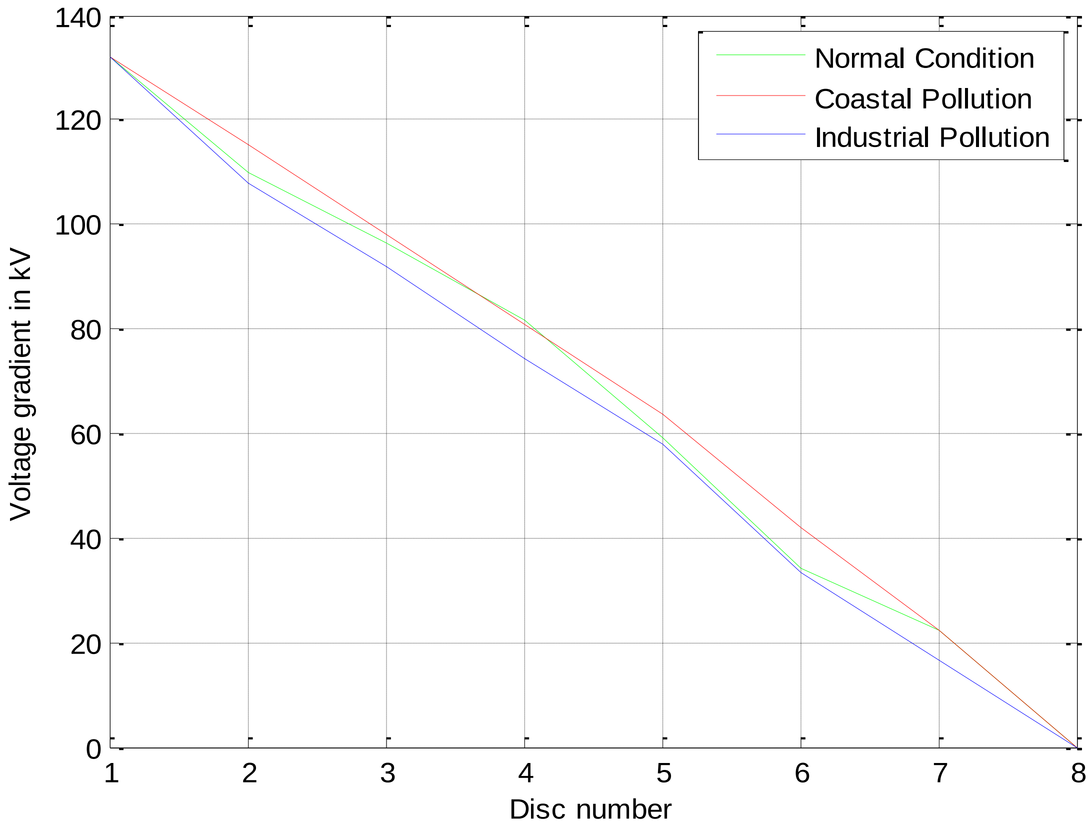


Fig. 18: Voltage gradient comparison in all the environment conditions

Fig. 19 shows the electric field comparison in all the environment conditions (in normal, coastal polluted and industrial polluted conditions). Here X-axis is leakage distance (meter) and Y-axis is electric field (kV/m). Leakage distance is the shortest between the two conducting parts of the insulator. Electric field point of view coastal polluted condition is more critical. Because electric field is more in this case, due to which the chances of breakdown of dielectric strength of air is more for it. As a result the occurrence of flashover and puncture is more here. It is also concluded that it is more dangerous for first unit which is near to the live conductor. It is least dangerous for normal condition. Therefore in polluted conditions it is preferred to use more number of insulator unit in the string of same voltage level.

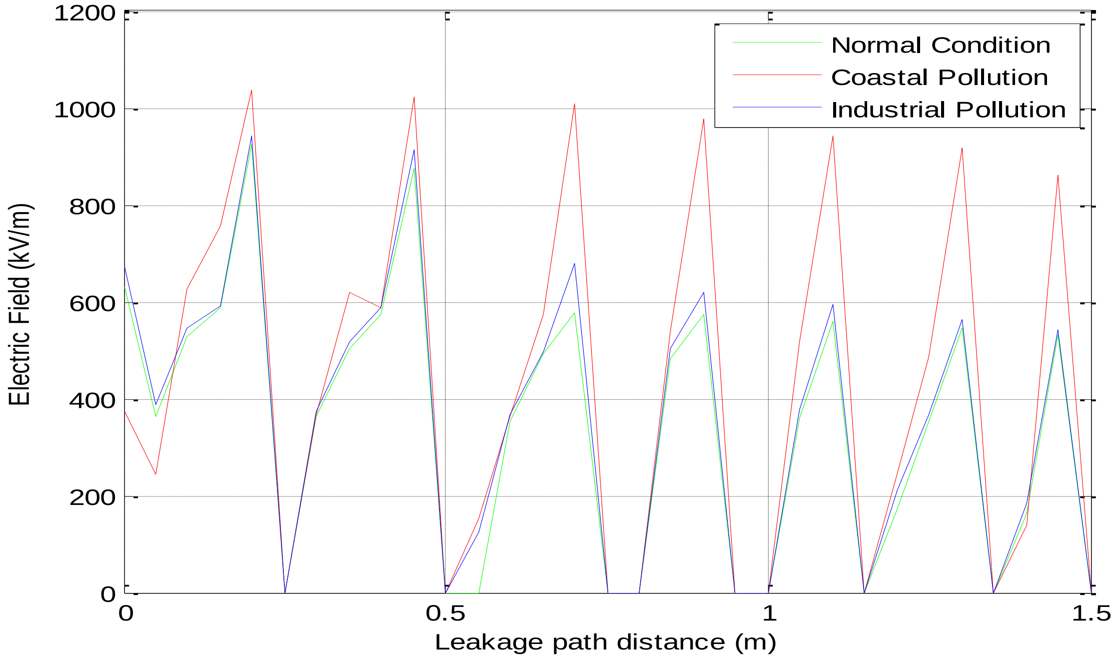


Fig. 19: Electric field comparison in all the environment conditions

CHAPTER-4

CONCLUSION AND SCOPE FOR FUTURE WORK

Here a comprehensive Ansys Maxwell software based electrostatic finite element analysis of 132 kV suspension type porcelain insulator string has been presented in normal condition, in coastal polluted condition and industrial polluted condition. It represents the voltage distribution, electric field distribution and electric field vector distribution without writing any equation. It shows the voltage and electric field at each and every point of the specified area in normal as well as in polluted condition. As voltage attends its maximum value on the insulator pin of the first unit (line end unit), so it is necessary to use a corona rings for high voltages in the case of composite insulators. From the simulation results, the maximum value of electric field has achieved in all the cases at the triple junction point (cement, porcelain and air). It is observed here the electric field along the leakage path of the composite insulator at the conductivity of each polluted layer has relatively the same patterns. The electric field increases with the increase in the polluted layer conductivity. From the simulation results electric field vector distribution, it is concluded that the electric field vector density is maximum in case of coastal pollution, as the conductivity of pollutant material and insulating material has higher values when it compare with the values of other conditions. Here a comparison between normal and polluted insulator string in the form of creepage voltage vs creepage distance in graphical manner has been presented and the creepage voltage in case of coastal pollutant condition has higher value than that of other two conditions.

SCOPE FOR FUTURE WORK

There is a lot of scope for future work in this project. There is further modelling and simulation in various cases of environmental conditions to study the flashover and puncture of insulator. Observe the voltage and electric field distribution for non-uniformly distributed pollutants, as it is more critical than uniformly polluted insulator string.

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APPENDIX

Dimension of single disc suspension insulator is

Diameter = 254mm

Height = 127mm

Leakage distance of single disc = 326mm

Supply voltage = 132 kV

Thickness of pollutant material in each disc = 0.07mm

Materials used ductile iron, forged iron, porcelain, cement, air and polluted material as the combination of salt and carbon monoxide all are with their normal properties.